TRIGGERED UNDERWATER CAMERAS FOR MARINE BIOLOGY

by

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S.B., Massachusetts Institute of Technology
(1957)

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF MASTER OF SCIENCE

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY
May 1959

Signature of Author ....
Department of Geology and Geophysics, May 20, 1959

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This thesis will be concerned with work done in the field of oceanography. The design and construction of the equipment was carried out in the Stroboscopic Laboratory at Massachusetts Institute of Technology. The sea use of the equipment was done in connection with Woods Hole Oceanographic Institute and the Institute Oceanographique at Monaco.

A submarine camera named the luminescence camera was designed and constructed for the purpose of investigating marine bioluminescence. The camera and strobe light unit contained an electronic control system which utilized a photomultiplier tube as the primary detector. Upon "seeing" a bioluminescent flash the camera is triggered and a picture of the organism causing the bioluminescence is obtained. This camera has been used extensively at sea and has produced many pictures.

Another submarine camera named the interruption camera was designed and constructed for the purpose of investigating the abundance of macroscopic life in the ocean. This camera contained an electronic control system which utilized a light beam and crystal photocell primary detector. When a macroscopic organism interrupts the light beam, the camera is triggered and a picture of the organism is obtained. This camera is more recent than the bioluminescence camera and has not as yet been used very much at sea.

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Abstract - Luminescence Camera

An instrument was designed and constructed for the purpose of causing the flashes of luminescence in the sea to trigger an underwater camera device and thus take photographs of the animals producing the flashes. A photomultiplier detector is utilized which, upon stimulation by the flash of a luminescent animal, triggers an electronic flash and camera combination. Simultaneously, a sonar pulse is emitted from an attached transducer, which announces that a picture has been taken and relays information to the surface concerning the depth of the instrument. After this the camera automatically advances its film to complete the cycle. The instrument described is entirely self contained and requires only mechanical support from the cable to the surface. It has been designed to operate at any depth down to 6000 meters. The length of film used during each lowering is sufficient for 800 frames. The instrument was operated successfully aboard the Research Vessel Crawford and the Coast Guard Cutter Yamacraw during the summer of 1957 and from the Research Vessels Calypso and Winnarretta Singer of the Institute of Oceanographique of Monaco in the Mediterranean Sea during the summer of 1958.

General Design - Luminescence Camera

This instrument was especially designed to investigate the light flashes previously observed by Clarke and Wertheim (1956), Clarke and Backus (1956), and Clarke and Hubbard (1958), while using the Bathyphotometer. Information from their work showed that the luminescence detector should be triggered by flashes with an irradiance of 10^{-5} u watts/cm^2 or greater in

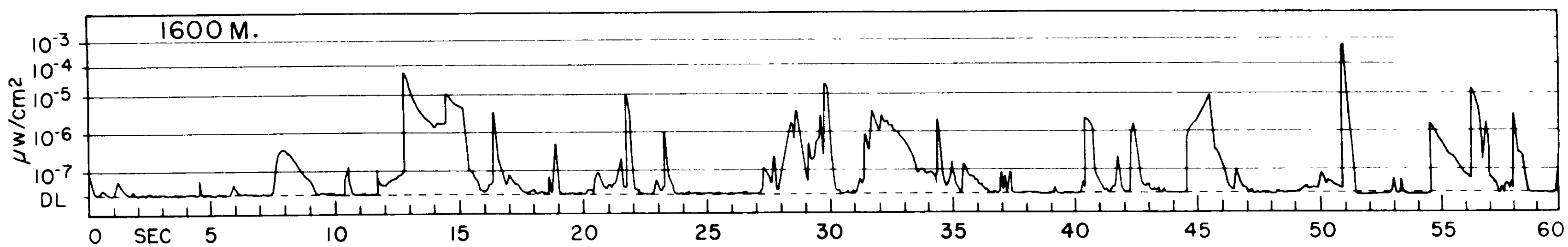

FIGURE 1. SECTION OF BATHYPHOTOMETER RECORD SHOWING BIOLUMINESCENCE

order to obtain a satisfactory number of photographs (fig. 1). Due to the high sensitivity demanded a photomultiplier trigger was required. This was designed so as not to be injured by direct sunlight or by the light flash emitted from the electronic lamp. The circuits are so designed that only pulses of light are accepted. Provision is made for manual pre-selection of the threshold level of the photomultiplier trigger.

The instrument is entirely self-contained thereby eliminating any dependence upon electrical conductors in the cable. The circuitry is such that the device can operate continuously for at least ten hours before the batteries need recharging. Mercury switches are employed so that the instrument can be loaded and stored in a prepared state.

The camera and film advancing circuitry are contained in one cylindrical housing, and the electronic flash and photomultiplier trigger are in another (fig. 2). These fit into a rigid cradle which fixes the overall geometry of the instrument. The cradle is so designed that each cylindrical house can be easily detached for facility in servicing and transportation.

Although the overall instrument is electrically self-contained, signals must be exchanged among its various units. Electrical pulses leave the flash unit, pass through the sonar, and then enter the camera unit. By utilizing the instrument ground, only one electrical lead-in is needed on each cylindrical housing.

The entire volume of water observed by the photomultiplier lies in the field of view of the camera and is illuminated by the electronic flash. Since many luminescent animals have translucent bodies, side lighting was deemed to be most desirable. Naturally a compromise must be made

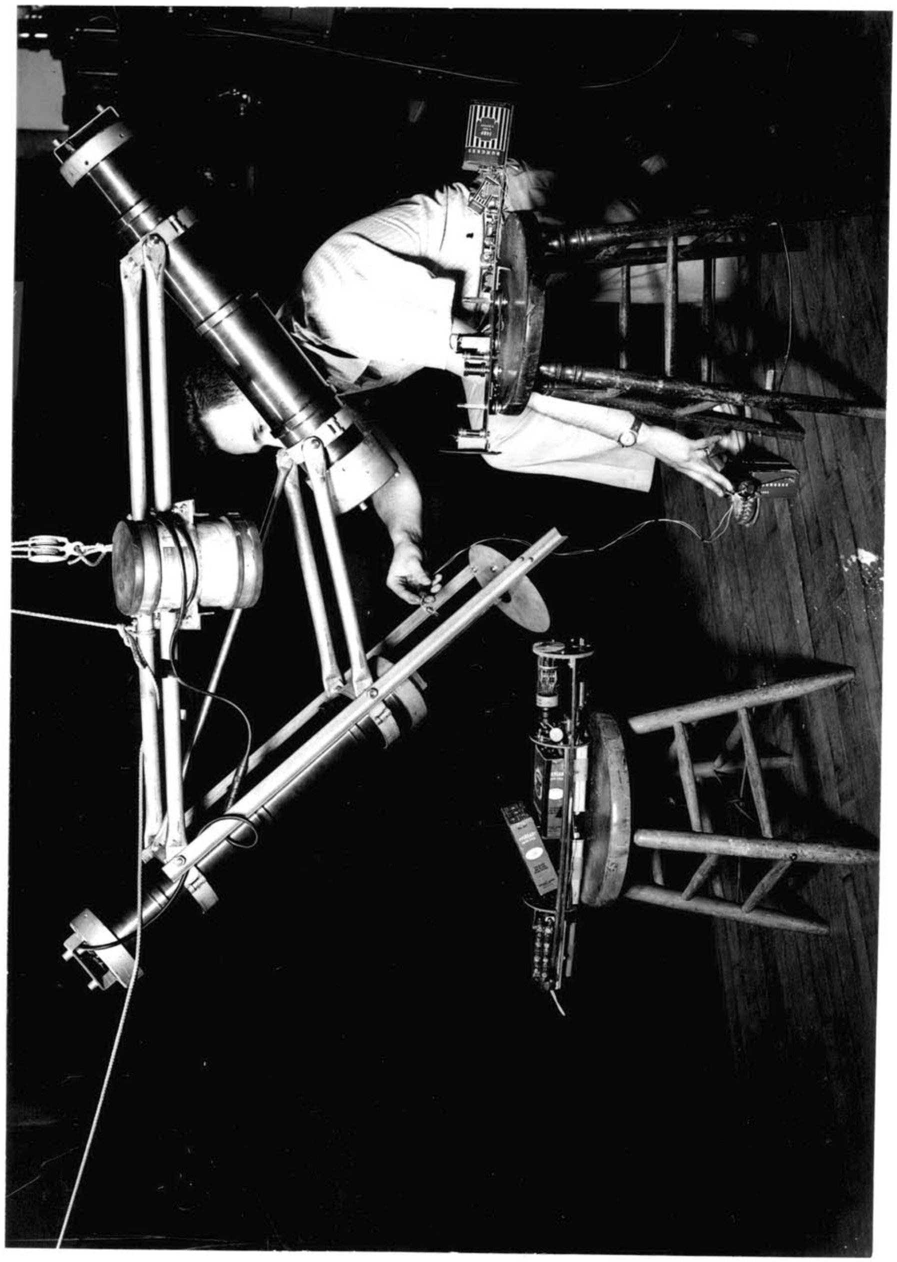

FIGURE 2. LUMINESCENCE CAMERA

concerning the field included and the magnification of the object photographed. Since most of the luminescent animals the photographic record of which was desired were expected to be less than 3 inches in length, an observed volume of about 1/10 of a cubic foot was decided upon. A second position of the tubes in the cradle allowed the camera to photograph only half of the volume observed by the photomultiplier, but produced twice the magnification. Each time a photograph was taken both an upward and downward ray are transmitted by the sonar. By recording the difference in arrival times of these rays at the surface, the depth of the instrument can be calculated. Since it is impractical to keep exact tally of the depth corresponding to each frame for the entire length of film, a small watch in a water-tight case was attached to the device in such a manner as to appear in each photograph. By the coordination of records on a time basis the depth, location, and other circumstances for each picture are determined.

Mechanical Design - Luminescence Camera

The cylindrical housings for the camera and flash units as well as the end plates are made of centrifugally cast 17-4 PH stainless steel. Heat treatment after machining brought the steel to a hardness of Rockwell 41. The cylinder has an inside diameter of 4.050 inches with a 3/8 inch wall thickness and a theoretical strength of 24,000 psi. The thinnest end plate is 1 inch thick with a theoretical strength of 40,000 psi. Each of the rear end plates on both units has a single electrical lead brought through it. A gland type fitting (Conax Mfg. Co., 4514 Main Street, Buffalo, New York) is utilized in conjunction with a plastic insulated solid wire. The use of a stranded wire in the gland may result in a leak through the space between the strands if the rubber wire does not completely seal. Single prong water-tight molded plugs (Joy Co., Henry W. Oliver Building, Pittsburg 22, Pa.) are attached to the solid wire on the outside of the end plate.

The face plate of the camera unit is 1.5 inches thick to form a rigid seat for the glass, and is provided with a 1 inch hole in the center through which the camera received light. Two concentric "O" rings form a water seal with the glass plate window. The plate glass window is 1 inch thick, and has the same outside diameter as the end plate. The surface of the glass is polished to increase its strength. The end plate of the flash unit is 1 inch thick and is provided with 1/2 inch holes spaced 2 1/4 inches apart. One of these is the receiving window of the photomultiplier and utilizes an "O" ring waterseal against a 1 inch thick plexiglass plate. The second hole is used for the connection of the electronic lamp housing.

The electronic flash lamp and associated spark coil are contained in a pyrex housing which is 12 inches long, 1 inch inside diameter, 1/4 inch wall thickness (Macalaster Bicknell Co., 243 Broadway, Cambridge, Mass.). This tube is closed with a rounded seal at one end and open with a flared edge ground flat at the other end. A metal clamp with a fiber insert fits over the flared end and secures the pyrex housing to the face end plate. A neoprene gasket provides a water seal between the flat end of the housing and the face end plate. The rubber gasket compresses under pressure and seldom has time to regain its original thickness when the instrument is retrieved. Therefore it is important to use a thin gasket and to provide some type of take-up mechanism on the metal clamp holding the tube. In this instrument the gasket is 1/32 inch thick and there are lock washers under the clamp holding bolts to insure a tension on it at all times.

The cradle for holding the two main tubes is constructed of 1 inch stainless steel tubing. Each tube is held in place by two clamps which may be opened and closed quickly by means of a thumb screw. The sonar transducer is of the crystal-in-oil type (EDO # X-18517) employing a rubber diaphragm on each end from which sonar beams are emitted. The transducer is positioned on the cradle so that the sonar beams are directed approximately vertically up and down.

The field of view of the photomultiplier is a right circular cone of about 25° with its apex located at the face plate of the flash unit. A baffle attached to the cradle truncates this cone at a distance of 10 inches from the face plate. A sensitivity zone is thus delineated into which a luminescent animal must enter in order that its flash will trigger the instrument.

Camera Design - Luminescence Camera

Many underwater cameras have been designed by putting a watertight case around a standard camera. Experience has shown however, that for great depths it is more advisable to design the camera to fit in the housing. The present instrument incorporates an "in-line" camera which has been specially designed by Edgerton for a cylindrical housing. The camera uses a standard 100 ft 35 mm motion picture reel. The film transportation is accomplished by using two "O" rings as belts from a motor to the sprocket shaft and to the take-up reel shaft. One main sprocket is used to meter the film. A microswitch operated by a cam on the sprocket shaft, is used to stop the film motion after each frame has been advanced. The take-up reel shaft is driven by a loose "O" ring belt that slips as the film builds up on the reel. The 6-volt motor (Hansen Manufacturing Co., Princeton, Indiana) turns at 18 rpm and is attached as a unit with the reducing gears to the camera plate.

Since the camera is shutterless, the electronic light flash takes the picture. The lens used is a Leitz Elmar f 3.5 with a 50 mm focal length. Since this lens with its adjustment cannot focus on points closer than 43 inches, lens extenders are used for each operating condition. Under "general" operating conditions the camera photographs a field 5 inches wide and 7 inches long, in the direction of the axis of the photosensitive cone. With "close up" operation the field is reduced to about half of this. Laboratory tests indicated that the most suitable aperture was f 16. The depth of field obtained at this aperture is sufficient to take in the entire photosensitive cone.

Electronics - Luminescence Camera

The circuit diagram of the photomultiplier trigger and electronic light is shown in figure 3 . Photomultiplier tube R.C.A. 6199 was chosen because of its high sensitivity, convenient size, and a spectral response peaked in the region of maximum transmission of sea water, which is also probably the region of most bioluminescent emission. The photosensitive surface of the S11 type is the same as that employed in the bathyphotometer. Were this not so, it would be impossible to form any correlation between the results of the two instruments. The device will be triggered by a pulse of light as small as 5×10^{-6} uw/cm^2 as measured with the bathyphotometer.

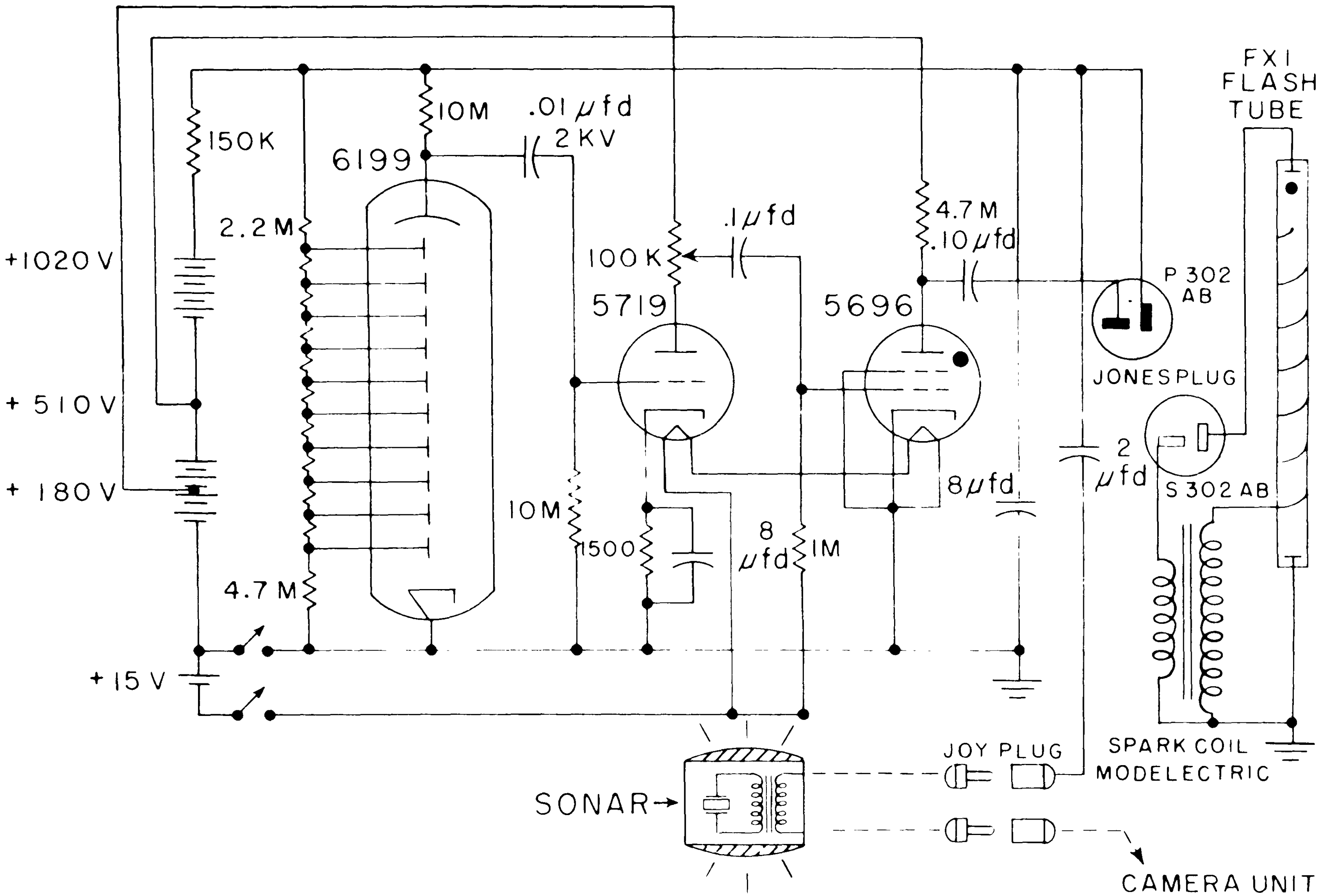

FIGURE 3. LUMINESCENCE CAMERA—FLASH UNIT

The high voltage is supplied by two 510 volt photoflash batteries (Eveready 497 or Burgess 320) placed in series. These were chosen because of their convenient size and 180 volt tap. The full 1020 volts, charging through the 150 k ohm resistor, are placed across the 8 ufd flash condenser and 2 ufd sonar condenser. These in turn hold up the voltage across the FX-1 electronic flash lamp (Edgerton, Germeshausen, and Grier, Incorporated) and the photomultiplier resistor bank. When the electronic flash lamp fires, these condensers discharge, and in so doing, drop the voltage across the photomultiplier bank to zero. This has the effect of temporarily desensitizing the photomultiplier and thus preventing it from injury by the high intensity electronic flash.

The photomultiplier resistor bank is composed of 2.2 M ohm resistors with the exception of a 4.7 M ohm resistor between the cathode and first dynode. The load imposed by this high resistance is negligible. Consequently the voltage across the photomultiplier is essentially the same as the battery open circuit voltage which makes for maximum sensitivity obtainable. Incremental voltage drops across the last few dynode resistors are of no consequence here since this is a trigger circuit rather than a linear amplifier.

The signal is developed across the 10 M ohm resistor in series with the photomultiplier anode. This very large value of resistance gives the stage a high sensitivity and serves to protect the photomultiplier from overload when subjected to a large value of ambient light. The photomultiplier generates a negative pulse across its anode resistor, whereas the thyratron can only be triggered by a positive pulse. Therefore a stage of voltage amplification is inserted between them and this serves to invert the phase.

The voltage amplifier utilizes a 5719 subminiature triode. This tube is used for missile circuitry and is supposed to be mechanically rugged and electrically stable. These factors, in addition to its small physical size, low quiescent power dissipation, and convenient filament rating influenced the choice of this tube.

The grid resistor used is 10 M ohm which provides a high degree of coupling to the photomultiplier. This has the advantage of producing a high sensitivity, but at the same time requires that the 5719 tube draws very little grid current. All the 5719 tubes used worked satisfactorily, but since the tube is being pushed beyond the manufacturers specifications, a "good" tube might have to be selected. The plate is fed from a 180 volt tap and passes through a 100 K ohm potentiometer. The output signal, developed across the potentiometer provides the manual sensitivity control.

Thyratron tube 5696 was chosen because of its small size and low filament dissipation. The thyratron is biased to cut-off by tapping off the negative side of the filament battery. A one M ohm resistor is injected here so as to provide the high impedance necessary in a thyratron grid circuit. The plate is fed from a 510 volt tap through a 1 M ohm resistor. A .25 ufd condenser in series with the spark coil primary is placed directly across the thyratron. When no signal current is applied, the thyratron is cut off. The full 510 volts is supplied to the plate and develops across the .25 ufd condenser. When a signal is applied, the thyratron fires. The condenser then discharges through the thyratron and energizes the spark coil. During the condenser recharge transient, most of the supply voltage falls across the 1M ohm resistor. This lowers the plate voltage of the thyratron and presents it from holding over.

One side of the spark coil secondary goes to a spiral of wire wound around the FXI xenon flash lamp. When energized, this ionizes the xenon and serves to set off the flash lamp. Once triggered the 8 ufd flash condenser discharges through the flash lamp. This produces a light flash with a peak intensity of .4 million horizontal candlepower and a time duration of 30 microseconds. After the electronic flash has occurred, the discharge condenser requires three seconds to recharge before another flash can be made.

The resistance of the xenon flash lamp drops to a very low value when it is energized. This property allows it to be exploited as a switch. Each time the lamp flashes, a path is completed between the sonar condenser, sonar transducer, and camera recycle unit. Consequently a 12.5 Kc impulse is emitted from the sonar transducer, and a syncronizing signal is sent to the camera unit for film recycle purposes. Filament power for both tubes is provided by eight Yardney LR 1 silver cells connected in series to produce 14 volts under load. Silver cells were used because of their high stored energy versus physical volume ratio.

The circuit diagram of the film recycle section of the interchangable camera unit is shown in figure 4. The synchronising signal is developed across the 1 ohm resistor. Duration of the signal is much too short to energize a relay and must be lengthened. This is accomplished by the 50 ufd condenser and diode combination. The relay employed is of the double coil polarized latching type. When either coil is energized in the direction of the indicated polarity, it will close and remain closed until either coil is energized in the reverse direction.

The film advance motor is mechanically coupled to a cam which activates

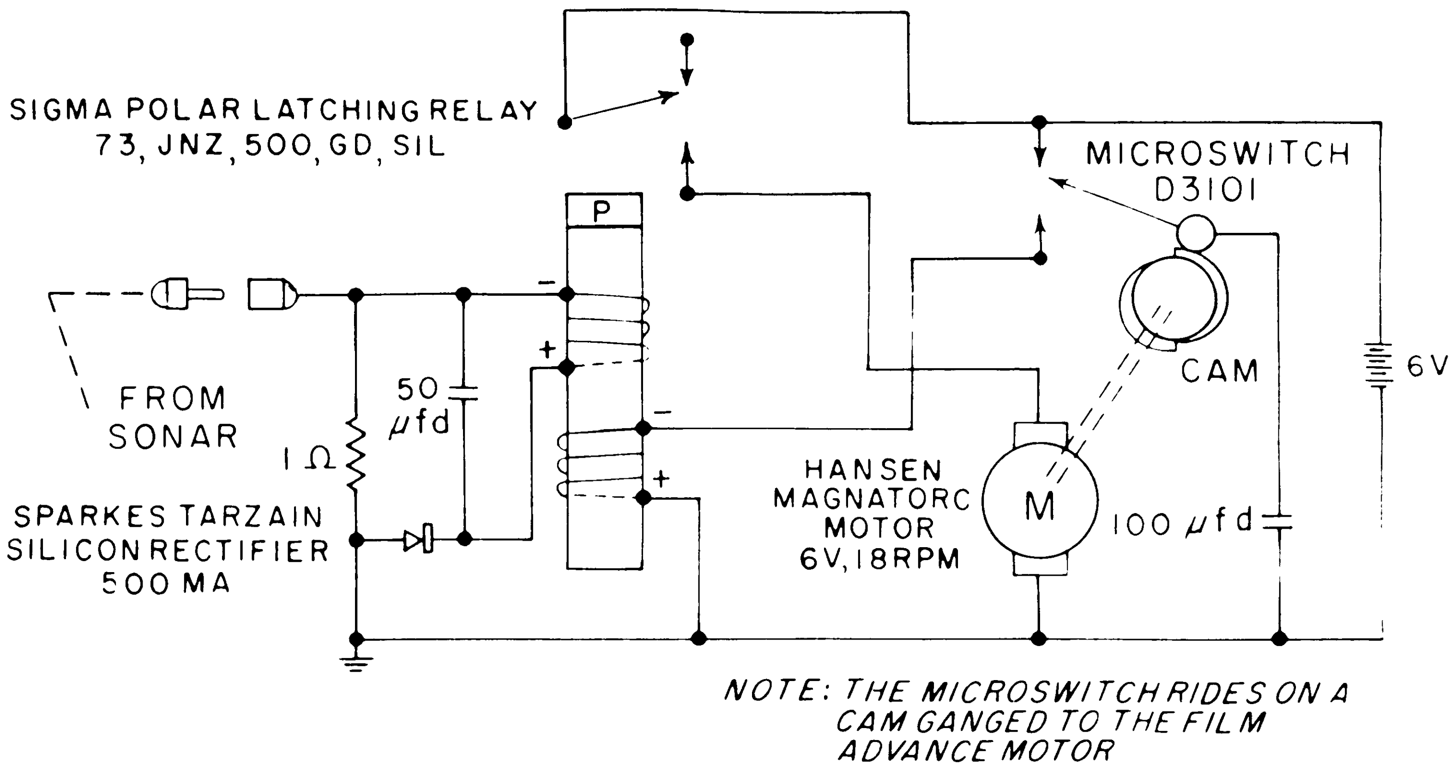

FIGURE 4. INTERCHANGABLE CAMERA UNIT
FOR USE WITH THE
LUMINESCENCE CAMERA
AND THE
INTERRUPTION CAMERA

a microswitch. The purpose of this cam is to inform the microswitch that the film has been advanced sufficiently. One six volt lantern battery (Burgess F4BP) is used to provide power for the film advance motor. This contains ample energy for the 800 recycle operations necessary to move the entire film through the camera.

At the beginning of the cycle the relay is open and the microswitch is in the down position. When the synchronizing signal is received, the relay closes and thus energizes the motor. While the motor is running, the cam causes the microswitch to assume the "up" position, and thus the 100 ufd condenser is charged. After the film has advanced sufficiently, the cam causes the microswitch to assume the "down" position, thus allowing the 100 ufd condenser to discharge into the relay. This causes the relay to open and consequently halts the film advance motor. The film is now in position, the relay has been reset, and the cycle is complete. The complete recycle process requires four seconds.

Operations at Sea - Luminescence Camera

The luminescence camera was operated from the Research Vessel Crawford of Woods Hole Oceanographic Institute and Coast Guard Cutter Yamacraw in the waters south of Woods Hole during the summer of 1957, and from the Research Vessels Calypso and Winnaretta Singer of the Institute Oceanographique of Monaco in the Mediterranean Sea during the summer of 1958. The instrument was used independently on certain occasions but improved results were obtained when it was employed in conjunction with the bathyphotometer and with the Precision Graphic Recorder (Knott and Hersey, 1956) for echo sounding.

The bathyphotometer used is a wide-range, logarithmic device sensitive enough to observe bioluminescence but not injured by a high intensity electronic flash. Since the light values received by the batnyphotometer at various depths are displayed on the Sanborn Recorder, it is possible to lower the camera to regions of maximum bioluminescent activity. In addition the simultaneous use of the photometer serves to verify that the luminescence camera is operating since the occurrence of each electronic flash is visible on the record of the Sanborn Recorder.

The precision graphic recorder used is of the high-resolution, sonar type. By recording the sonar impulse emitted from the luminescence camera this device is able to discern the distance from the ship to the instrument and hence its vertical depth when the wire angle is low.

The camera may be loaded and unloaded without the use of a dark room, but opening the camera on deck causes about 3 ft. of film to be fogged. In this case about 25 frames should be run through before and after the lowering.

Open cameras at sea can become filled with warm, humid air. As a result, when the cameras are lowered into the cold sea, moisture condenses on the inside of the glass window, destroying its photographic quality. Every effort must be made to keep the inside of the camera case dry. When a camera emerges from the cold sea water, it should not be opened until it has warmed to air temperature since otherwise moisture would immediately condense over the entire interior. Thermal equalization can be hastened by bathing the camera housing in warm water.

The film used was Kodak plus X in 100 ft. spools. This was processed at sea using a Morse tank in order that the results could be evaluated immediately.

The operation of the entire instrument may be conveniently tested on deck by exposing it to a flashlight, match, cigarette, or other small light source. The electronic flash should be seen and the recycle of the film and the click of the sonar transducer should be heard.

A convenient test for the recycle circuit is to apply a six volt negative pulse between the Joy plug input and the housing ground. This technique may also be used to advance the film when desired. The electronic light section of the photomultiplier and electronic light unit may be checked by short circuiting the grid of the thyratron to ground. This should produce an electronic flash.

A portable test light was designed and constructed for facility in determining sensitivity of the instrument. This device consisted of a 700 ufd condenser charging up to 22.5 volts and then discharging through a 30 ohm rheostat into a 3 volt tungsten flashlight bulb. The light pulse generated was found to have essentially the same shape as that of many luminescent animals. A wooden calibration box was constructed. This fits over the head of the photomultiplier unit and provides a light tight chamber into which the portable test light may be introduced. The rheostat on the portable test light is then varied until the threshold of the photomultiplier trigger is found. The portable test light is then placed in the calibrating box of the bathyphotometer and its value determined by that instrument.

Sample photograph of animals which took their own pictures by means of the luminescence camera are reproduced in Figs. 5 - 12. The SIPHONOPHORE (about 6 centimeters in diameter), shown in figure 5 was obtained in

August 1957 aboard the Research Vessel Crawford about 170 miles east of Cape Hatteras at a depth of about 100 meters.

The EUPHAUSID (about 2 centimeters in diameter), shown in figure 6, was taken in February 1958 aboard the Ex Coast Guard Cutter Yamacraw at a depth of 300 meters.

The CTENOPHORE (about 3 centimeters in diameter), shown in figure 7, was taken in February 1958 aboard the Coast Guard Cutter Yamacraw at Latitude 28° 16' N and Longitude 79° 41' W at a depth of 10 meters.

The MEDUSA (about 1 centimeter in diameter), shown in figure 8, was obtained in February 1958 aboard the Coast Guard Cutter Yamacraw, at Latitude 24° 58' N and Longitude 85° 01' W at a depth of 100 meters.

The EUPHAUSID (about 1 1/2 centimeters long), shown in figure 9, was obtained in February 1958 aboard the Coast Guard Cutter Yamacraw, at Latitude 23° 52' N and Longitude 82° 05' W at a depth of 50 meters.

The MEDUSA (about 1 centimeter in diameter), shown in figure 10, was obtained in February 1958 aboard the Coast Guard Cutter Yamacraw, at Latitude 24° 58' N and Longitude 85° 01' W at a depth of 360 meters.

The CEPHALOPOD (about 2 centimeters long) shown in figure 11, was obtained in June 1958 aboard the Research Vessel Calypso, at Latitude 43° 31' N and Longitude 7° 23' E at a depth of 10 meters.

The MEDUSA (about 7 centimeters in diameter) shown in Figure 12, was obtained in August 1958 aboard the Research Vessel Crawford, in the Gulf of Maine, at a depth of 1000 meters.

FIGURE 5. PHOTOGRAPH OF A SIPHONOPHORA (ABOUT 6 CENTIMETERS IN DIAMETER) AT A DEPTH OF ABOUT ONE HUNDRED METERS. OBTAINED 170 MILES EAST OF CAPE HATTERAS USING THE LUMINESCENCE CAMERA.

FIGURE 6. PHOTOGRAPH OF A EUPHAUSID (ABOUT 2 CENTIMETERS LONG) AT A DEPTH OF THREE HUNDRED METERS. OBTAINED ABOUT 100 MILES EAST OF CAPE HATTERAS USING THE LUMINESCENCE CAMERA.

FIGURE 7. PHOTOGRAPH OF A CTENOPHORE (ABOUT 3 CENTIMETERS IN DIAMETER) AT A DEPTH OF TEN METERS. OBTAINED 100 MILES SOUTH EAST OF JACKSONVILLE, FLORIDA USING THE LUMINESCENCE CAMERA.

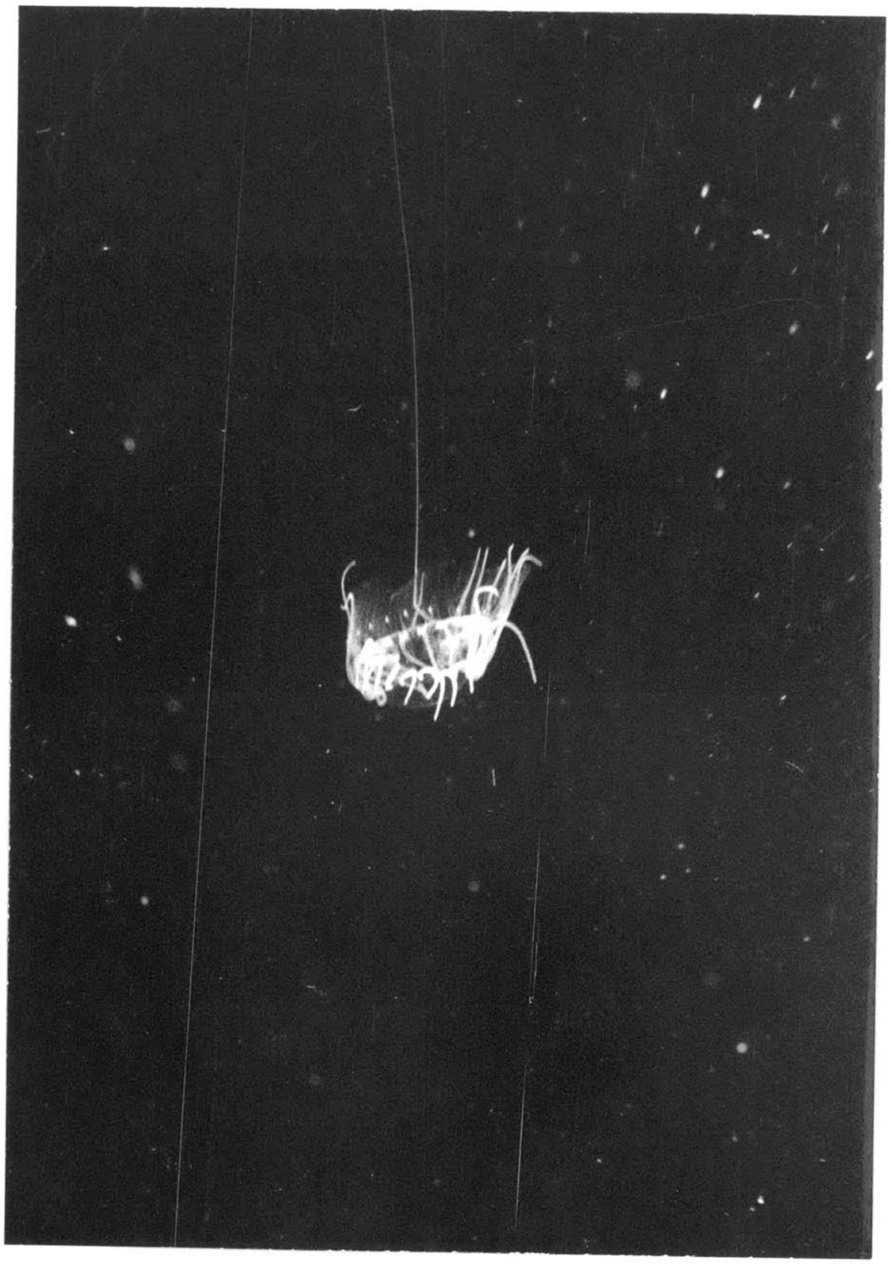

FIGURE 8. PHOTOGRAPH OF A MEDUSA (ABOUT 1 CENTIMETER IN DIAMETER) AT A DEPTH OF ONE HUNDRED METERS. OBTAINED IN THE EASTERN GULF OF MEXICO USING THE LUMINESCENCE CAMERA.

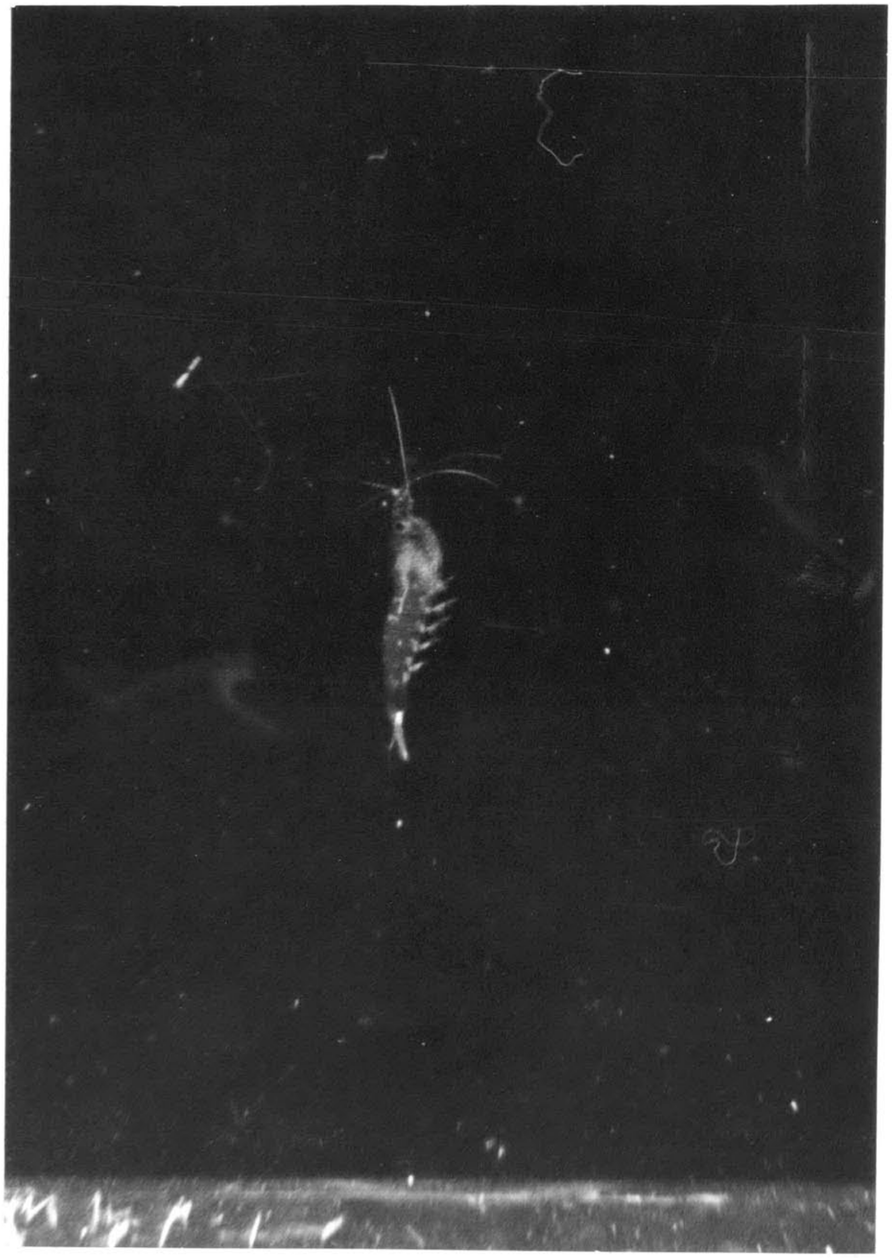

FIGURE 9. PHOTOGRAPH OF A EUPHAUSID (ABOUT 1 1/2 CENTIMETERS LONG) AT A DEPTH OF FIFTY METERS. OBTAINED IN THE STRAITS OF FLORIDA USING THE LUMINESCENCE CAMERA.

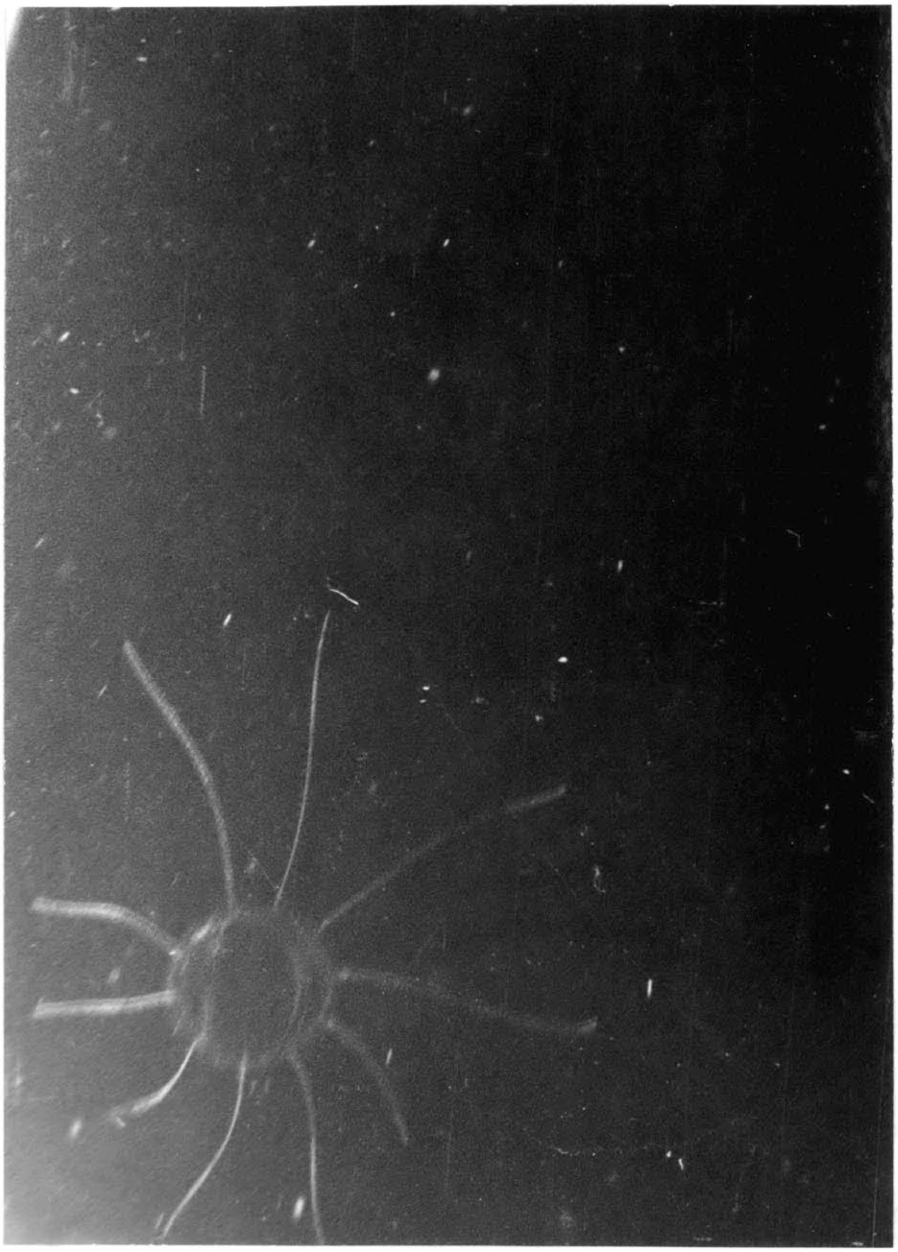

FIGURE 10. PHOTOGRAPH OF A MEDUSA (ABOUT 1 CENTIMETER IN DIAMETER) AT A DEPTH OF THREE HUNDRED AND SIXTY METERS. OBTAINED IN THE EASTERN GULF OF MEXICO USING THE LUMINESCENCE CAMERA.

FIGURE 11. PHOTOGRAPH OF A CEPHALOPOD (ARMS ABOUT 2 CENTIMETERS LONG) AT A DEPTH OF TEN METERS. OBTAINED IN THE MEDITERRANEAN SEA SOUTH OF FRANCE USING THE LUMINESCENCE CAMERA.

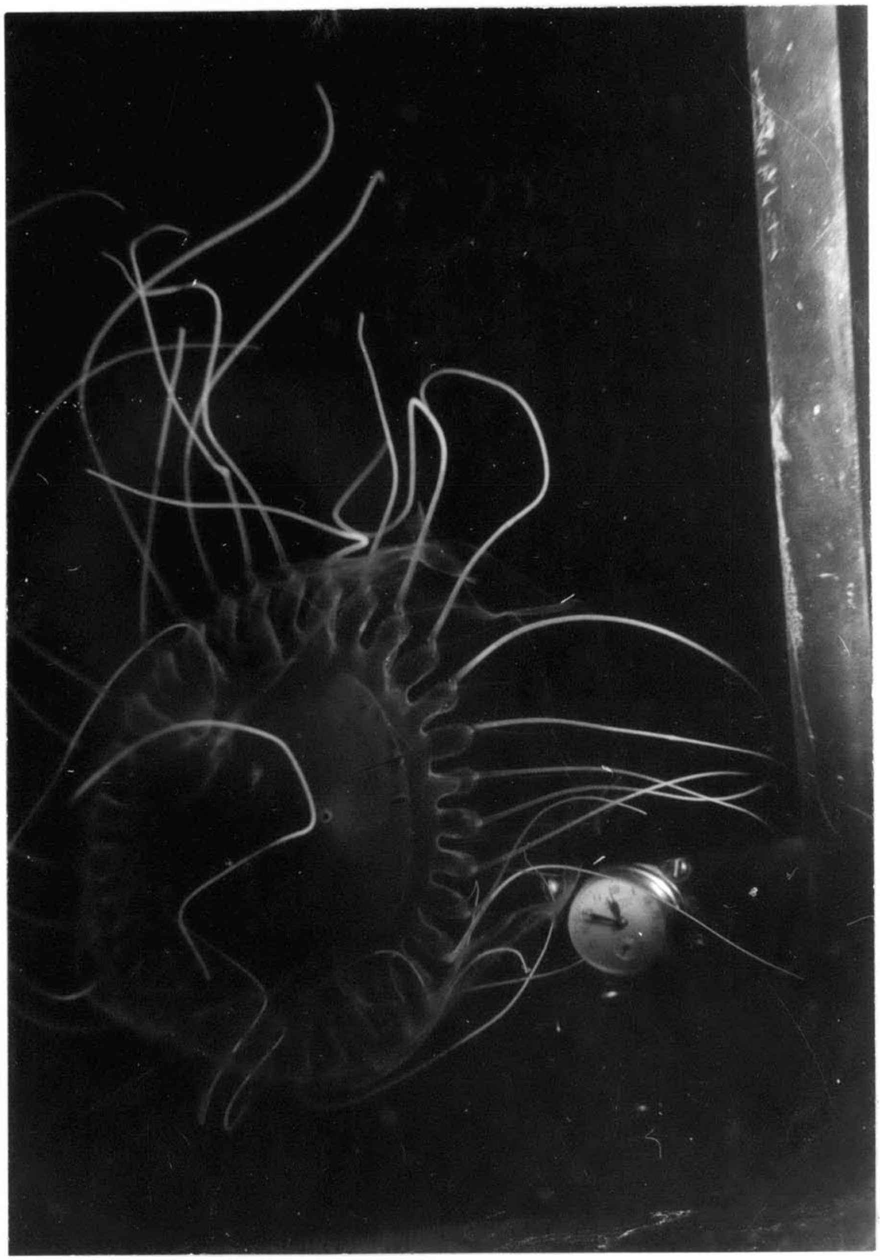

FIGURE 12. PHOTOGRAPH OF MEDUSA (ABOUT 7 CENTIMETERS IN DIAMETER) AT A DEPTH OF ONE THOUSAND METERS. OBTAINED IN THE GULF OF MAINE USING THE LUMINESCENCE CAMERA.

Abstract - Interruption Camera

An instrument was designed and constructed for the purpose of photographing macroscopic life at medium depths in the ocean. The device utilizes a trigger system which consists of a light beam impinging upon a semiconductor photocell. When a macroscopic organism interrupts the light beam, it triggers the electronic flash and camera combination. Simultaneously, a sonar pulse is emitted from an attached magnetostriction transducer, which announces that a picture has been taken and relays information to the surface concerning the depth of the instrument. After this the camera automatically advances its film to complete the cycle.

The instrument described is entirely self contained and requires only mechanical support from the cable to the surface. It has been designed to operate at any depth down to 2000 meters. The amount of film contained in the camera is sufficient for 800 photographs during a single lowering.

The instrument was operated with limited success aboard the Research Vessel Crawford during the summer of 1958. At this time the color of the light beam used in the trigger system was white. Subsequently, laboratory tank tests were run with common fish in order to determine their response to various light beam colors. These limited tests indicated that for these particular nondescript fish, passage through a light beam was objectionable. It appeared that infra red light was less objectionable than red light and very much less objectionable than white light and therefore the instrument was modified accordingly. Using the new infra red light beam arrangement, many pictures of fish in the tank have been obtained.

General Design - Interruption Camera

This instrument is designed for the general purpose of photographing macroscopic life in the ocean. Rather than simply taking pictures at random a method of sensing when a subject is present is employed. This is achieved by having a light beam and photosensitive detector arranged so that a photograph is taken when the light beam is interrupted.

A crystal photocell is used as the photodetector because of its adequate sensitivity and small physical size. A cadmium sulphide crystal (Clairex Type CL-2) is used for white light and a cadmium selenide (Clairex Type CL-3) is used for deep red and infra red light. A standard two cell flashlight bulb and reflector are used in the light source to produce a "white" light beam which is 3 cm in diameter. To obtain a deep red light beam a Kodak Wratten #29 filter which opens up at 6000 angstroms is placed over the light source. To obtain an infra red light beam a Kodak Wratten #89B filter which opens up at 6800 angstroms is placed over the light source.

Provision is made for manual pre-selection of the size interruption of the light beam which will be required to trigger the camera. At maximum sensitivity the camera will trigger, for all color light beams and appropriate crystals, when 1% of the light beam is interrupted. This can be caused by a totally opaque subject obstructing 1% of the area of the light beam or a subject of 99% transmittance obstructing the entire area of the light beam. The time constant for the photocells is about 15 milliseconds which should be sufficiently fast for this application.

The camera with film advance circuitry, and the electronic flash with trigger control circuitry, are contained in separate large cylinders which constitute the camera unit and the flash unit respectively. These fit into a rigid cradle which is so designed that each cylindrical house can be easily detached for facility in servicing and transportation. The semiconductor photocell and the incandescent light are contained in separate small cylinders which constitute the underwater light receiver and underwater light source respectively. These are fixed to the ends of separate "arms", the other ends of the "arms" being attached to the cradle. The instrument is shown in figure 13.

The instrument is entirely self-contained thereby eliminating any dependence upon electrical conductors in the cable. The circuitry is such that the device can operate continuously for at least eight hours before the batteries need recharging. Mercury switches are employed so that the instrument can be loaded and stored in a prepared state.

Although the overall instrument is electrically self contained, signals must be exchanged among its various units. The power for the incandescent light in the underwater light source is located in the flash unit. Electrical pulses must be transmitted from the semiconductor photocell in the underwater light receiver to the trigger control circuit which is located in the flash unit. Other electrical pulses must leave the flash unit, pass through the sonar, and then go to the film advance circuit which is located in the camera unit. By utilizing the instrument ground, only one electrical lead-in is needed on the underwater light receiver, the underwater light source, and the camera unit and three electrical lead-ins are needed on the flash unit.

The light beam is 1 meter long and 3 centimeters in diameter. It is located in the same plane as the camera unit and the flash unit, which are

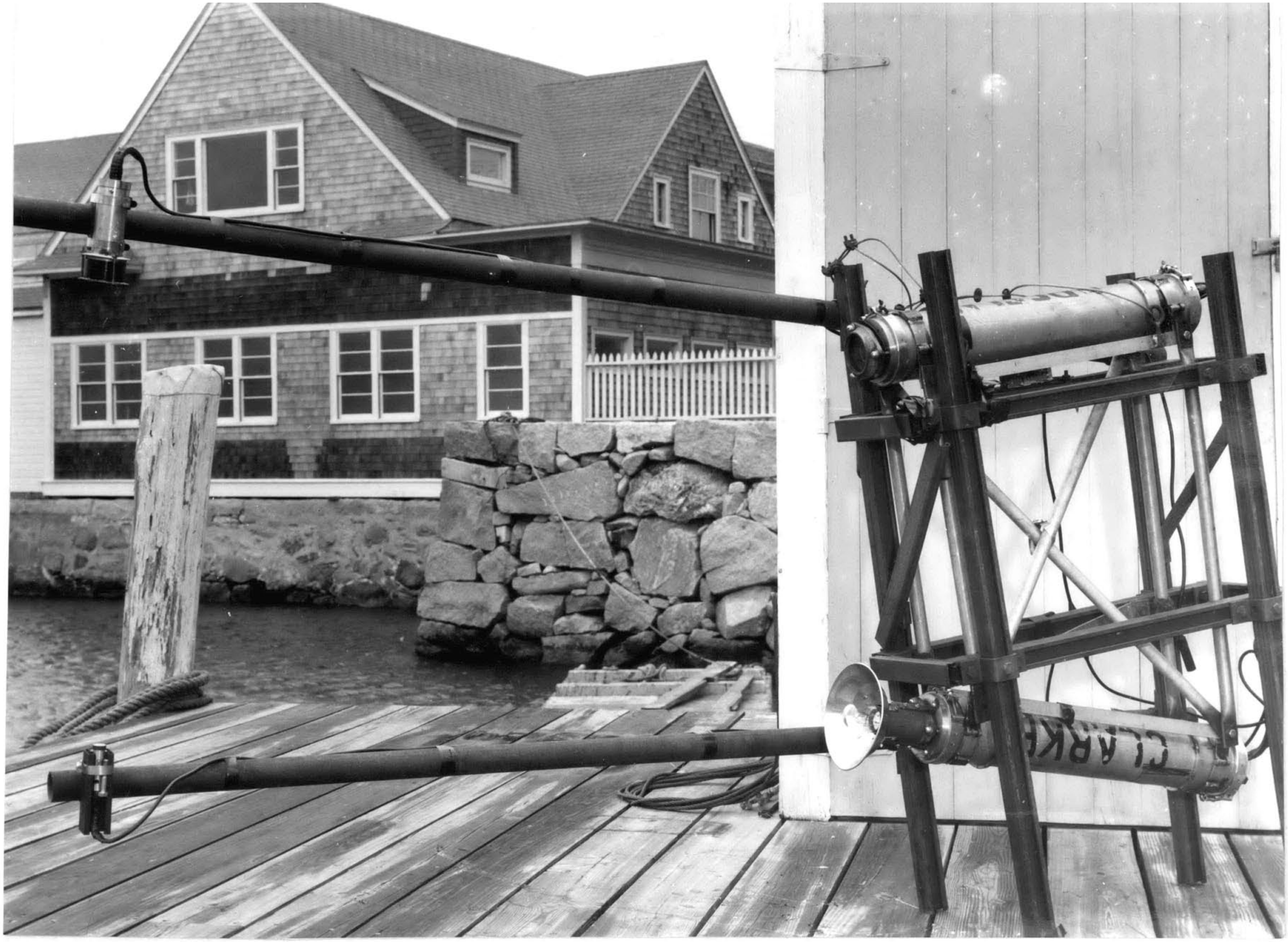

FIGURE 13. PHOTOGRAPH OF THE INTERRUPTION CAMERA.

sub parallel, and at a distance of about 2 meters from the camera window. When the instrument is suspended in its normal operating position the light beam is vertical. The camera is pointed toward the center of the light beam and at that distance has a field of 1.3 meters in the vertical direction and 2 meters in the horizontal direction. Consequently the entire photo-sensitive trigger volume is photographed.

Since many of the macroscopic organisms were expected to be opaque pseudo front lighting was deemed to be most desirable. Therefore the camera unit and flash unit are sub parallel. At the location of the light beam the center of illumination will be slightly above the point at which the camera is pointed.

Each time a photograph is taken both an upward and downward ray are transmitted by the sonar. By recording the difference in arrival times of these rays at the surface, the depth of the instrument can be calculated.

Mechanical Design - Interruption Camera

The material used for the cylindrical housings for the camera and flash units as well as the end plates was type 304 stainless steel. The cylinders are made out of schedule 40 seamless stainless steel pipe of iron pipe size four inches, which comes off the shelf with an inside diameter of 4.027 inches, an outside diameter of 4.500 inches and a wall thickness of .237 inches. This inside diameter is not large enough to prevent the film reels in the camera from binding and it is necessary to increase it to 4.050 inches (American Hollow Boring Co., Erie, Pa.). The theoretical crushing pressure for the cylinders is 3,500 psi and they have been successfully tested in a pressure chamber to 3,000 psi.

The rear end plate on the camera unit has one, and the rear end plate on the flash unit has three electrical leads brought out through it. A gland type fitting (Conax Mfg. Co., 4514 Main St., Buffalo, New York) is utilized in conjunction with a plastic insulated solid wire. The use of a stranded wire in the gland may result in a leak through the space between the strands if the rubber wire does not completely seal. Single prong water-tight molded plugs (Joy Co., Henry W. Oliver Building, Pittsburg 22, Pa.) are attached to the solid wire on the outside of the end plates.

The face plate of the camera unit is 1 inch thick and is provided with a 1 5/16 inch hole in the center through which the camera received light. A plate glass window 1 1/4 inches thick fits over this through hole and is held in place by a metal clamp. A neoprene gasket is utilized to make the water seal between the glass window and the stainless steel face plate. This rubber gasket compresses under pressure and seldom has time to regain its original thickness when the instrument is retrieved. Therefore it is important to use a thin gasket and to provide some type of take up mechanism on the metal clamp holding the glass plate. In this instrument the gasket is 1/32 inch thick and there are lock washers under the clamp holding bolts to insure a tension on it at all times.

The face plate of the flash unit is identical with the face plate of the camera unit. The through hole is used for the electrical connections to the electronic flash lamp, which is in a pressure housing fitting over it. The electronic flash lamp and the associated spark coil are contained in a pyrex housing which is 6 inches long, 1.5 inches in inside diameter, and has a 1/4 inch wall thickness (Macalaster Bickness Co., 243 Broadway, Cambridge, Mass.). This tube is closed with a rounded seal at one end and open with a flared edge ground flat at the other end. A metal clamp with a fiber insert fits over the flared end and secures the pyrex housing to the face end plate. A neoprene gasket provides a water seal between the flat end of the housing and the face end plate. What has been previously mentioned concerning the compression of the neoprene gasket applies here and consequently the gasket is 1/32 inch thick and lock washers are used on the metal clamp.

For both the flash and camera units, the waterproof seals between the end plates and cylinders are achieved by using "O" rings. A single "O" ring grove is cut in the plane face of the end plate and the "O" ring in this grove seals against the lip or edge of the cylinder.

The underwater light receiver cylinder is made out of a solid rod of stainless steel which is 2 1/2 inches long and 3/4 inches in diameter. A hole 7/16 inch in diameter is drilled along the axis to form a chamber for the semiconductor photocell. The window end is terminated by a plexiglass plug which has an "O" ring set into it for the water seal. The rear end is terminated by a single packing gland through which an electrical conductor is led out. This has withstood a laboratory pressure test of 3,000 psi.

The underwater light source cylinder is made out of schedule 40, iron pipe size 1.5 inch, seamless stainless steel pipe. The length is 4 1/2 inches, the outside diameter is 1.9 inches and the wall thickness is .145 inches. The window end is terminated by 3/4 inch plexiglass plate which has an "O" ring seal against a stainless steel flange welded flush along one end of the cylinder. A reflector taken from a common two cell flashlight and a flashlight bulb (G.E. PR-6) comprise the light source. The rear end is terminated by a 3/8 inch thick stainless steel plug, employing an "O" ring seal, and in which is set a single packing gland through which an electrical conductor is led out. This has withstood a laboratory pressure test of 3,000 psi.

The cradle for holding the flash unit cylinder and camera unit cylinder is constructed of 1 inch stainless steel tubing. Each cylinder is held in place by two clamps which may be opened and closed quickly by means of a thumb screw. This cradle was then enclosed in a framework of Unistrut (George Wahn Co., Unistrut Division, 99-103 High St., Boston, Mass.) in order to provide an extremely rigid base for the support of the "arms" which position the underwater light source and the underwater light receiver 2 meters in front of the camera. The "arms" are simply black iron pipes which are 2 inches in diameter. The sonar transducer is of the magnetostriction type. It is attached to the stainless steel cradle in such a position so that the sonar beams are directed vertically up and down.

Camera Design - Interruption Camera

Many underwater cameras have been designed by putting a watertight case around a standard camera. Experience has shown however that for great depths it is more advisable to design the camera to fit in the housing. The present instrument incorporates an "in-line" camera which has been specially designed by H. E. Edgerton for a cylindrical housing. The camera uses a standard 100 ft. 35 mm motion picture reel. The film transportation is accomplished by using two "0" rings as belts from a motor to the sprocket shaft and to the take-up reel shaft. One main sprocket is used to meter the film. A microswitch operated by a cam on the sprocket shaft, is used to stop the film motion after each frame has been advanced. The take-up reel shaft is driven by a loose "0" ring belt that slips as the film builds up on the reel. The 6-volt motor (Hansen Manufacturing Co., Princeton, Indiana) turns at 18 rpm and is attached as a unit with the reducing gears to the camera plate.

Since the camera is shutterless, the electronic light flash takes the picture. The lens used is a Summaron f 3.5 with a 35 mm focal length. This is set to focus on a subject which is 2 meters in front of the camera window when in water. At this distance the field is 1.3 meters in the vertical direction and 2 meters in the horizontal direction. Laboratory tests indicated that the most suitable aperature was f 16.

Electronics - Interruption Camera

The circuit of the trigger control and electronic flash is shown in figure 14. The photoconductor used is a crystal photocell because of its adequate sensitivity, small size and ruggedness. The Clairex Type CL-2 is a cadmium sulphide crystal which has a peak spectral response at 5,200 angstroms and is used in conjunction with the "white" light beam. The Clairex Type CL-3 is a cadmium selenide crystal which has a peak spectral response at 7,500 angstroms and is used in conjunction with the deep red and infra red light beams. While the transmittance of infra red light of 7,500 angstroms is only about 5 percent per meter in sea water, the sensitivity of the Clairex Type CL-3 is about six times that of the Clairex CL-2 and consequently the "white" light beam trigger is about three times as sensitive as the infra red light beam trigger. However, when the instrument is set for maximum sensitivity, an obstruction of 1 percent of the light beam will trigger the camera for any color light beam used.

The incandescent light source is a flashlight bulb of the General Electric Type PR-6. This uses two Eveready Energizers as its source of power. Laboratory tests have shown that this arrangement is capable of lasting over eight hours on one set of batteries even at temperatures as

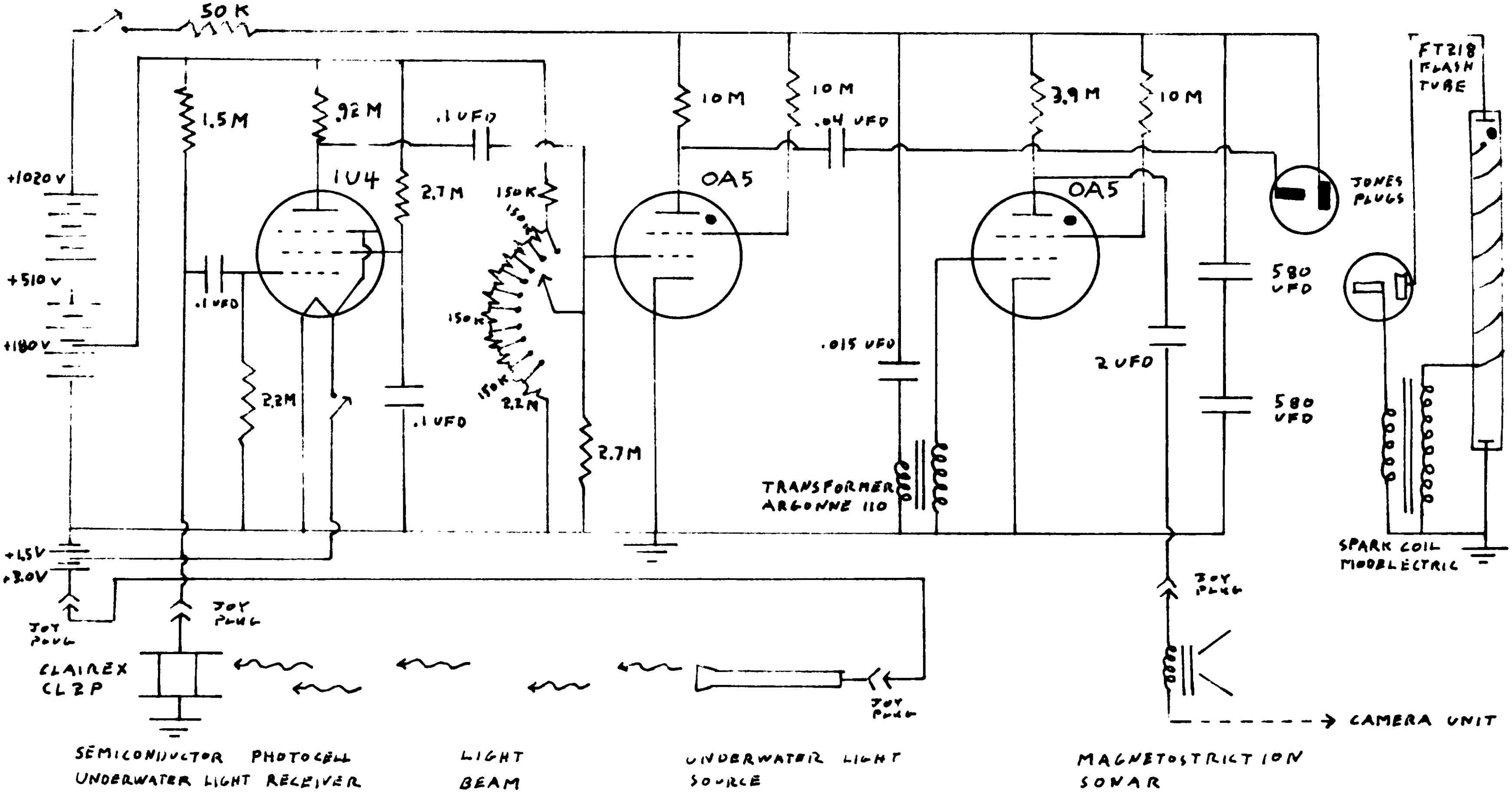

FIGURE 14. INTERRUPTION CAMERA — FLASH UNIT

low as 34 degrees Fahrenheit. No filter is employed for "white" light. For deep red light a Wratten #29 filter which transmits wavelengths of 6,000 angstroms and over is used. For infra red a Wratten #89B filter which transmits wavelengths of 6,800 angstroms and over is used.

As a circuit element the photocell acts as a resistor which varies in value with applied illumination. In complete absence of light the cell resistance is very high, in the order of megohms. When the "white" light beam is used in seawater, the Clairex Type CL-2 crystal has a resistance of about 50 kilohms. When the infra red light beam is used in seawater, the Clairex Type CL-3 crystal has a resistance of about 150 kilohms.

The high voltage is supplied by two 510 volt photoflash batteries (Eveready 497 or Burgess 320) placed in series. These were chosen because of their convenient size and 180 volt tap.

The voltage amplifier utilizes a IU4 sharp-cutoff pentode. This is a miniature type which is made for portable use and requires low filament power. The voltage gain is over 150. When an object leaves the light beam, a negative pulse is placed on the control grid of the IU4. This pulse is then amplified and inverted and placed on the control grid of the first OA5.

The OA5 is a trigger tube of the strobotron variety which was chosen because of its small size, cold cathode design, and high stand-off voltage rating. The quiescent current drawn is very low, being only 100 micro-amperes through the keep-alive grid.

The first OA5 is a trigger tube for the flash lamp. A .04 ufd condenser in series with the spark coil primary is placed directly across the strobotron. When no signal is applied to the control grid, the strobotron is cut off. The full 1020 volts is supplied to the anode and develops across the .04 ufd condenser. When a signal is applied to the control grid, the strobotron fires. The condenser then discharges through the strobotron and energizes the spark coil. During the condenser recharge transient, most of the supply voltage falls across the 10 megohm resistor in the anode circuit, which lowers the anode voltage and prevents the strobotron from holding over. Manual sensitivity control is provided by varying the bias on the control grid.

One side of the spark coil secondary goes to a metal band around the FT 218 xenon flash lamp (General Electric Co.). When energized, this ionizes the xenon and serves to set off the flash lamp. Once triggered the 580 ufd flash condensers discharge through the flash lamp. This produces a light flash with a peak intensity of 2 million horizontal candlepower and a time duration of 400 microseconds. After the electronic flash has occurred, the discharge condenser requires twenty seconds to recharge before another flash can occur.

The second 0A5 is a triggertube for the sonar transducer. The .015 ufd condenser in series with the step up transformer is charged to the voltage appearing across the flash lamp. Each time the flash lamp fires, this condenser discharges through the primary of the transformer. Since the secondary of this transformer is connected to the control grid of the second 0A5, this tube also fires each time the flash lamp fires. When the second 0A5 fires, a path is completed between the 2 ufd sonar condenser, the magnetostriction sonar transducer, and the camera recycle unit. Consequently a 12.5 Kc impulse is emitted from the sonar transducer, and a synchronizing signal is sent to the camera unit for film recycle purposes.

The circuit diagram of the film recycle section of the interchangable camera unit is shown in figure 4. The synchronizing signal is developed across the 1 ohm resistor. Duration of the signal is much too short to energize a relay and must be lengthened. This is accomplished by the 50 ufd condenser and diode combination. The relay employed is of the double coil polarized latching type. When either coil is energized in the direction of the indicated polarity, it will close and remain closed until either coil is energized in the reverse direction.

The film advance motor is mechanically coupled to a cam which activates a microswitch. The purpose of this cam is to inform the microswitch that the film has been advanced sufficiently. One six volt lantern battery (Burgess F4BP) is used to provide power for the film advance motor. This contains ample energy for the 800 recycle operations necessary to move the entire film through the camera.

At the beginning of the cycle the relay is open and the microswitch is in the down position. When the synchronizing signal is received, the relay closes and thus energized the motor. While the motor is running, the cam causes the microswitch to assume the "up" position, and thus the 100 ufd condenser is charged. After the film has advanced sufficiently, the cam causes the microswitch to assume the "down" position, thus allowing the 100 ufd condenser to discharge into the relay. This causes the relay to open and consequently halts the film advance motor. The film is now in position, the relay has been reset, and the cycle is complete. The complete recycle process requires four seconds.

Operations at Sea - Interruption Camera

The Interruption Camera was operated from the Research Vessel Crawford in the waters south of Woods Hole during the summer of 1958.

The camera may be loaded and unloaded without the use of a dark room, but opening the camera on deck causes about three feet of film to be fogged. In this case about 25 frames should be run through the camera before and after the lowering by manually interrupting the light beam on deck.

Open cameras at sea can become filled with warm, humid air. As a result, when the cameras are lowered into the cold sea, moisture condenses on the inside of the glass window, destroying its photographic quality. Every effort must be made to keep the inside of the camera case dry. When a camera emerges from the cold sea water, it should not be opened until it has warmed to air temperature since otherwise moisture would immediately condense over the entire interior. Thermal equalization can be hastened by bathing the camera housing in warm water.

The film used was Kodak Plus X in 100 ft. spools. This was processed at sea using a Morse tank in order that the results could be evaluated immediately.

A convenient test for the recycle circuit isto apply a six volt negative pulse between the joy plug input and the housing ground. This technique may also be used to advance the film when desired.

It is desirable to have a Precision Graphic Recorder (Knott and Hersey, 1956) present on the ship though it is by no means necessary. By recording the sonar impulse emitted from the Interruption camera, this device is able to discern the distance from the ship to the instrument and hence its vertical depth.

The SIPHONOPHORE (about 25 centimeters in diameter) shown in figure 15 was obtained in August 1958 using the interruption camera aboard the Research Vessel Crawford, in the Gulf of Maine, at a depth of probably about 200 meters.

FIGURE 15. PHOTOGRAPH OF SIPHONOPHORE (ABOUT 25 CENTIMETERS LONG) AT A DEPTH OF PROBABLY ABOUT TWO HUNDRED METERS, OBTAINED IN THE GULF OF MAINE USING THE INTERRUPTION CAMERA.

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Acknowledgements

The author greatly appreciates the fact that H. E. Edgerton of M. I. T. very generously donated the facilities of the Stroboscopic Laboratory at M. I. T. where the electronic work was performed, and contributed unstintingly his valuable time, energy and advice toward the completion of this project. The author also is indebted to G. L. Clarke of W.H.O.I. for his numerous suggestions as a biologist concerning the desirable features to be incorporated into the design of this instrument. V. MacRoberts of M. I. T. ably assisted in the construction of these instruments. L. Hoadley of W.H.O.I. assisted in the pressure testing of the underwater housings. The machine work was done in the machine shop of the Research Laboratory of Electronics at M. I. T. under the supervision of foreman J. Keefe.

I wish to thank the many people who helped us during the testing of the Luminescence Camera at sea on the R/V Crawford, CGC Yamacraw, R/V Calypso, and R/V Winnarretta Singer, in particular J. B. Hersey, J. Cousteau, C. J. Hubbard, A. Laban, W. A. Richardson, E. E. Hays, R. C. Stross, D. B. Clarke and T. Stetson.

I wish also to thank the many people who helped us during the testing of the Interruption Camera at sea on the R/V Crawford and during the laboratory tank tests, in particular R. C. Stross, B. Connover, N. Dulaney, J. Perry and H. Fuller.